Chapter 16
Role of Telecommunications in Precision Agriculture

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ABSTRACT

Precision agriculture has been made possible by the confluence of several technologies: geographic positioning systems, geographic information systems, image analysis software, low-cost microcomputer-based variable rate controller/recorders, and precision tractor guidance systems. While these technologies have made precision agriculture possible, there are still major obstacles which must be overcome to make this new technology accepted and usable. Most growers will not do image processing and development of prescription maps themselves but will rely upon commercial sources. There still remains the challenge of storage and retrieval of multi-megabytes of data files for each field, and this problem will only continue to grow year by year. This chapter will discuss the various wireless technologies which are currently being used on three proof-of-concept farms or areas in Mississippi, the various data/information intensive precision agriculture applications which use wireless local area networking and Internet access, and the next generation technologies which can immensely propel precision agriculture to widespread use in all of agriculture.

INTRODUCTION

Multispectral image-based precision agriculture technology is beginning to have widespread use in row crop production agriculture in the United States, particularly in the cotton belt. Companies such as InTime, Inc.1 (InTime, 2007), located in Cleveland, Mississippi, USA, are providing image-based products from which clients have access to scout maps derived from multi-spectral images. InTime uses Geospatial System's Inc. multispectral image cameras mounted on fixed-winged aircraft to obtain their image information (GSI, 2007). Specific scout maps target different plant or soil characteristics such as overall plant biomass, differences in soil type, and differences in fertilizer nitrogen uptake. The scout maps are used to determine rates of plant growth regulators, insecticides, defoliants, herbicides, or fertilizer to apply to the plants. Utilizing InTime's Web-based Crop-Site, growers and consultants can easily transform their scout maps into vehicle/controller prescription files that allow for chemical rates to be varied automatically with minimal operator inputs.

The information products generated by such activity, as described previously, can easily be expressed as multi-megabyte sized data files, especially when geographic information system (GIS) technology is used. In almost all situations, multispectral-image based maps are geo-referenced with pixel sizes in the 0.5 meter to 1 meter range generating large data files for the applications derived from these maps. The application maps are also generally geo-referenced for use by the geographic positioning systems (GPS)-based controllers on the farm equipment. For a 500 ha field, application maps can easily be generated which are from 1 to 5 megabytes in size or larger.

Many controller manufacturers today use PC cards or similar technology which has to be hand-carried from the farm base of operations to the equipment in the field and inserted into the controller (Raven Industries, 2008). Conversely, after the application has been made by the equipment (planting, fertilizer application, pesticide application, etc), the PC cards have to be manually collected and taken to the operations base to have the as-applied map uploaded into the farm computer. While many medium and small farms are not affected by this information movement process since the farm manager/owner is also the equipment driver, larger farms which have many pieces of equipment are often scattered over 50 km from one side of the farm land to the other, or even greater distance. The distances involved from the farm base station to the equipment in the field presents an operations problem for growers since when they are involved with precision applications not only must they travel to and from the fields where the equipment is located they must also find the equipment in the field which can often be two or more kilometers across to deliver and pick up the PC cards containing information. This type of operation can easily take a person three or more hours per day just to deliver and/or pick up the data cards.

When time critical operations are involved in delivery of pesticide application maps to the spray equipment controller, this problem becomes even more exacerbated. Our research in early-season plant bug control has shown that from the time the multispectral image is taken by the airplane to the time the spatially variable insecticide is delivered to the spray equipment no more than 48 hours should elapse (Willers et al., 1999). The optimal time is no more than 24 hours. Obviously, there is a better way to solve this time constraint/labor problem than using people for hand carrying PC cards.

Wireless local area network technology is a practical solution to movement of information to and from farm machinery which use GPS-guided precision application controllers. Low-cost wireless network solutions are available and are beginning to see widespread use in the United States. Commercial cell telephone networks are beginning to offer medium–speed Internet access via their cellular telephone towers.

Another technology which is becoming very widely used in the United States is the use of precision guidance on farm application machinery. This technology has proved it worth in labor savings alone by removing the tedium from equipment operators so that they can monitor the application operation to ensure seeds or chemicals are being applied as the equipment moves across the field, allowing the operator to stay longer in the field without the exhaustion which accompanied pre-precision guidance operations. Another tangible benefit from precision guidance cultivation is the recovery of lost row acreage which has been estimated as high as 10% of large field area. This recovery for cotton production on larger plantations has been estimated to pay for the precision guidance system in as little as one year. Many precision guidance systems use the 900 MHz public spectrum to send the signals from the GPS base station to the farm equipment to allow up to centimeter accuracy in the placement of farm application machinery in operation.

This chapter will discuss the various wireless technologies which are currently being used on three proof-of-concept farms or areas in Mississippi, the various data/information intensive precision agriculture applications which use wireless local area networking and Internet access, and the next generation technologies which can immensely propel precision agriculture to wide spread use in all of agriculture.

CURRENT STATE OF AFFAIRS

All farms engaged in row crop production agriculture have extensive information available on their farm operations, crop inputs in terms of seed used and fertilizers applied, soil types, soil fertility, pesticides applied and weather information. Some farms are more organized than others and have all this information developed in computerized databases. Modern production agriculture requires that the aforementioned information and much more be available for not only preseason and in-season decision making, but also for many regulatory purposes required by state and federal government agencies and by seed companies which provide genetically modified varieties used in current practices, especially in cotton production.

The National Cooperative Soil Survey began more than a century ago. Soil databases began to be accumulated by the US Department of Agriculture for the entire US in earnest in the 1940's, 50's and 60's in terms of soil maps whereby soil types were identified and classified by agents of the Soil Conservation Service. These agents would walk the fields, take soil cores manually, and identify broad areas on soil maps by soil type. Today, one can obtain detailed soil maps for each county in a state and generally rely on the placement of these soil types within crop fields. Since August 2005, soil maps and associated data and information have been available through a geographic information system called the Web Soil Survey (WSS). The newest version of the WSS is at http://Websoilsurvey.nrcs.usda.gov.

In the past, soil fertility has been obtained by taking representative soil cores from each major soil type within a field, where soil type was obtained from the maps mentioned previously, and sending the soil samples to a state or private laboratory for analysis to determine N, P and K content.

Yield histories on a field or worst case farm basis have been obtained for management purposes. The advent of private and commercial access to the Global Positioning System (GPS) has changed not only the type of record keeping but has made the level of record keeping much more detailed. Most of the data records were paper records of field histories, planting data, fertilizers applications, chemical applications, fuel usage, equipment usage, and yield data which were kept on a field or farm basis. Only in the last 15 years have these data been migrated from the paper environment to the computer database environment.

Early use of telecommunications on farms was primarily limited to farm headquarters communicating to equipment operators and farm personnel using citizens-band radios, licensed two way radios, and paging equipment.

GPS AND PRECISION STEERING

In the 1970s and 80's the US Military began launching a series of 24 satellites into low orbit above the earth with a pattern of orbits such that most of the time at least 4 to 6 satellites are in line-of-sight to an observer on the earth's surface

(Daly, 1993). These satellites emit radio signals with extreme precision time information so that with appropriate receiving equipment, one can determine one's location on the surface of the earth. This system is known as the Global Positioning System or GPS. Today using what is known as differential signal correction one can determine one's position within plus or minus one meter of the true location with hand-held devices. Going even further, when a secondary radio system is used with GPS signals and the secondary system's location is precisely known, position accuracies within plus or minus one centimeter can be determined. This later system is known as a survey-grade GPS system and is the basis for auto-steering technology which is used in precision guidance of farm machinery.

In the 1970's and 80', software began to be developed to take advantage of satellite imagery so that precision maps could be obtained and manipulated. As GPS became available, this feature was integrated into the software systems so that ground features collected manually using GPS sensors could be added to the maps. This allowed the soil maps which were collected by the Soil Conservation Service and the US Geological Survey to be digitized and converted into spatially sensitive computer maps. Several break thoughs happened during this time which affected the use of the data contained in the old soil maps. Land-leveling was found to be advantageous especially concerning the application of irrigation technology (Walker, 1989). Land-leveling required the use of laser technology (one-way communication) to automatically raise or lower machinery used in the leveling process. This process also changed the morphology of the soil types in the field so that field had to be re-sampled to determine their new soil type. GPS technology was used to map the boundaries of the soil types in the fields to much higher level of accuracies. Millions of acres of land were land-leveled. Even farms that were not land-leveled began to have their field re-sampled using GPS to determine more accurate soil-type boundaries within the fields.

Within the last 10 years, precision guidance or auto-steering systems have become widespread in use (Lessiter, 2006). These systems make use of GPS and an on-site beacon system typically using the 900 MHz unlicensed spectrum to broadcast location and timing signals to field machinery used in precision operations. A typical auto-steer system will have two to three satellite GPS receivers mounted on the field vehicle and a receiver antenna for the geo-referenced beacon system, which can be as far as 50 km from the machinery. These systems typically use frequency hopping radios and a fairly low transmission rate such as 125 to 250 kbps. According to the physics of signal propagation, the lower the transmission rate the further the signal propagates. Again this type of system is a one-way transmission from the satellites and the beacon down to the receivers on the field equipment. Signals from the auto-steer system allow tractors, sprayers, combines, and harvest equipment to navigate a predetermined path with centimeter accuracy. Auto-steer systems allow extended hours of operation by operators without the fatigue associated with non-auto-steer vehicles. Operators can pay more attention to the operation of the equipment to assure the operation is being carried out properly, i.e., seed planting equipment or chemical applicators are working properly and not clogged. Another huge benefit of using auto-steer systems is the recovery of lost acreage. Conventional row crop operations lose area because the operator can not precisely steer the equipment 100 % of the time so rows are made with less precision, typically loosing 10% of the field. This 10% can now be recovered and made productive. Large cotton plantations typically can pay for the cost of auto-steer systems within the first year of operations just from the recovery of lost acreage and the increase in productivity from that area.

REMOTE SENSING VIA AIRCRAFT

Another facet of the precision agriculture technology package is the availability of timely images of row crops within the growing season. Because of the timeliness factor, satellite imagery is of very limited to no use at all, because from the time the image is acquired to the time it is made available for decision making months have elapsed. Imagery acquired via fixed-winged aircraft has become commercially available widely in the US over the last five years. Companies such as InTime, Inc can provide 24 to 48 hour response time to image requests making this technology available for rapid response pest management as well as longer term crop management decisions. Images acquired for use in crop and pest management typically involve four layer images using red, blue, green, and infrared filtered images which are spatially and geo-rectified. From these four layers, image analysis software such as Imagine and ARCView can be used to construct prescription maps which can be used to make decisions about fertilization, irrigation, pesticide applications, application of plant growth regulators, and harvest aid chemical applications. Since most farms are by definition remotely located and do not have access to the Internet, these images and application maps currently have to hand-carried to the farm headquarters for distribution to farm managers and crop and pest consultants. The lack of high speed digital data communication is a major bottleneck in the promotion and acceptance of image-driven precision agriculture technology. This scenario, however, is beginning to change.

PRESCRIPTION FARMING

Even without the help of remote sensing and imaging technologies, precision agriculture has been in use for over 15 years and is becoming wide spread in use. The advent of the low cost micro-controllers based on the microcomputer has made this possible. With computer technology becoming available on the farm beginning in the middle 1980's, farm record keeping was a natural advance from paper records to digital database technology. As computers became more and more powerful and hard discs became ever larger in size, the computer became more than just a good way to keep records to satisfy income tax requirements and EPA regulations on chemical and pesticide usage. Software became available in the early 1990's which allowed farm managers the capability to specify planting density, chemical application rates, and fertilizer application rates which corresponded to their historical records of soil type, soil fertility, cation exchange capacity, field yield data, and weather conditions. The microcontrollers on the field machinery coupled with GPS sensors could then make the seed, chemical, or fertilizer applications required by the specific site requirement of the area within each field (DuPont et al., 1999). Harvest equipment using sometimes the same microcontrollers and GPS sensors could record the yield of the field as the harvesters moved across the field generating a spatially-referenced yield map, which then could be used to help plan the next season's prescriptions. The only missing link at this time is the aerial imagery to gauge how the crop is progressing within the season so that mid-course corrections could be applied to maintain or enhance yields.

The primary method for conveying prescriptions from either the farm managers computer where prescriptions were generated or from a third party commercial prescription generator's computer was then and still is to a large extent today the use of PC Cards. The PC Cards would have to be hand-carried to each specific controller located of the farm machinery and inserted into the appropriate slot whereby the application program would then be uploaded and the machinery would carry out the prescription operation.

Today, growers have the controllers and equipment which can carry multiple varieties of seeds and plant these varieties according to soil conditions by soil fertility by soil types or by specific area (AgLeader Technologies, 2008). The GPS signal coupled with the controller and application software determine which variety to plant and how many seeds per row foot to plant. Chemicals applied at planting can be applied at different rates. During the growing season spray equipment can apply as many as six chemicals concurrently by different rates assuming there is no incompatibility between chemicals.

Aerial chemical applications are also beginning to use variable rate technology with GPS sensor technology and high speed controllers changing the chemical application rate as the aircraft speeds across the field.

For many growers the use of PC cards does not cause any problems. However for large farms which have thousands of acres and often are noncontiguous, the PC card limitation is a problem. The farm manager or other skilled personnel have to hand-deliver PC cards to each piece of equipment when precision operations are called for. Many times the farm equipment is in operation and has to be located. All of this takes time away from skilled personnel who could be more productive performing other tasks. If the wrong card is delivered to the wrong piece of equipment, that equipment will have to wait until it receives the right card; again lost productivity or worse the wrong chemical is applied. Major controller vendors have yet to move away from proprietary closed systems to open systems which have telecommunication capability.

Most growers today do not have the training or capability to perform image analysis and application map generation and do not wish to invest in equipment, software or training to be able to do so. They instead will rely on third party prescription generators to perform these operations. Companies exist which can perform all of the image acquisition, image analysis, and application map generation in-house as a turnkey operation. Other companies exist which can acquire the aerial imagery and hand this imagery off to other companies which perform the image analysis and application map generation. There are also some large farm operations which can perform their own image analysis and application map generation.

Another important aspect of prescription farming is ground truthing. The first component of ground truthing is to record actually what was applied or done where. Because of soil conditions, equipment failure, weather, etc, some field operations may not be carried out as required by the application map. In this case, the controller records what is actually done at each time frame and location and this is stored in the controller as an as-applied map. It is vitally important to retrieve this information from the controller and archive the data at the farm headquarters computer because when it comes time to analyze what was done and what was the outcome this information may explain any anomalies.

The second part of ground truthing occurs during the growing season. When imagery is used to generate application maps, the crop and pest management consultants and their helpers have to stay intimately involved in the decision making loop. While imagery has been shown to reduce by as much as 40% of the observations required by consultants to confirm, extend, or compact zones of treatment predicted by the imagery, these still need to be confirmed by boots on the ground. The imagery maps, often in the form of Normalized Difference Vegetative Index (NDVI) maps (Schowengerdt, 1997), can be used to preselect optimum observation or scouting points within fields. The observer navigates to these points using hand-held GPS sensors and confirms the observation or reports discrepancies. These data are then relayed back to image analysis expert who combines the observations and generates the final application map. This operation is another strong requirement for high speed bidirectional data transmission to the farm and within the farm.

In today's farm world most of the events where we are discussing the movement of information or data, it is movement by hand-carrying the data or information to a central site where the data can be loaded in to a base operations computer or downloaded into a microcontroller from a PC Card. The entire US is covered by satellite Internet access which is unsymmetrical in nature. There are fairly high speed downlinks which can reach as high as 1 mbps but the uplink is much slower and peak out at 150 kbps. All of these speeds are relative to the amount of traffic on the shared link and can be much less than the top speeds. As mentioned before, by definition, the great majority of farms are remote and do not have access to ground-based high speed Internet and will not for the immediate and medium term future. The cost of running fiber optic cable is too high and copper will not meet the needs. Telephone modems are not reliable enough to transmit hundreds to thousands of megabyte-sized image files.

CURRENT AND FUTURE TELECOMMUNICATION CAPABILITIES

Current Services

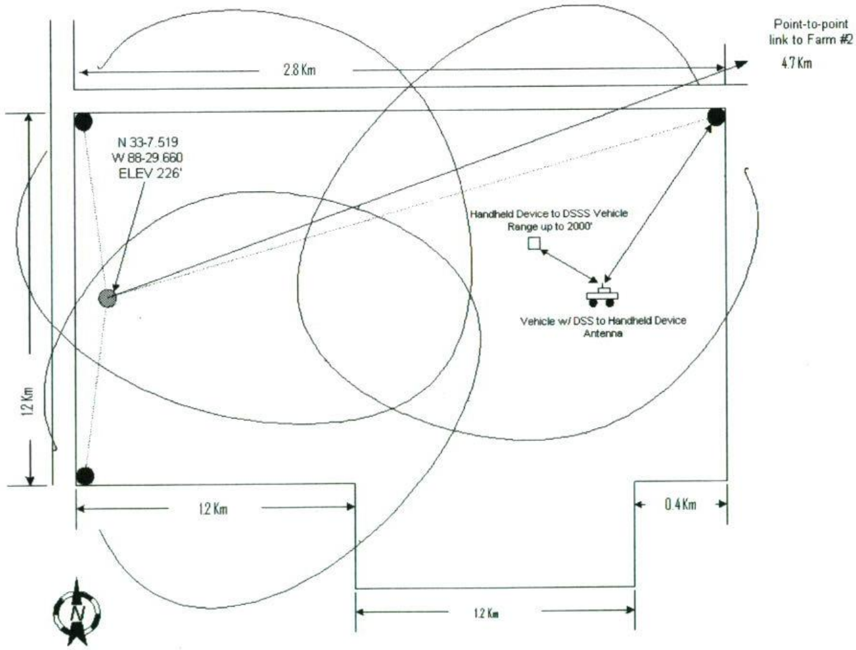
Satellite capabilities have the possibilities of being significantly upgraded, but have the main limitation of being point-to-point and not covering mobile operations without expensive servo equipment to maintain antenna pointing direction. While providing the link to the Internet for the farm operations centers, satellite is not the answer for communicating with farm machinery and pest and crop consultants in the field.

Unlicensed broadband applications have been in use for over 22 years in the US. Most of the applications have become know as WIFI and use the unlicensed 900 MHz and 2.4 GHz bands with some application in the 5 GHz bands, though these are mainly used as links to the 2.4 GHz and 900 MHz sites. Unlicensed WIFI has two major problems for providing the Internet access to farm operations center; these are range and line-of-sight. Rules for use of WIFI were set by the FCC (FCC, 1985). These rules specified the frequencies to be used and the power of the signal to be broadcast. The main problem for 2.4 GHz broadband is the power of the signal is limited to 1 watt so as not to cause problems with adjacent licensed bands above and below 2.400 to 2.483 GHz. The physics of the problem is simple. When you are trying to send high speed data signals, the more data you send at the same power density the shorter the range will be. Further, at 2.4 GHz, the signal propagation is blocked completely by buildings, trees and foliage so line-of-sight is required for relatively long distances. The 5.0 to 5.8 GHz spectrum behaves comparatively the same as the 2.4 GHz spectrum. The 900 MHz spectrum behaves much more favorably than either 2.4 GHz or 5.0 GHz spectrum, but there is less of it. The 900 MHz spectrum ranges from 900 to 928 MHz. Because the frequency is lower, the signal propagates much better at the same 1 watt power density. Non-line-of-sight signals can be reliably transmitted up to a 10 km radius using horizontally polarized antennae. After that, line-of-sight is required. Using line of sight conditions, a central antenna can broadcast reliable signals to a transceiver with a yagi antenna up to 65 km away. Because of the spectrum limitation and FCC rules, the maximum user data rate is about 2 mbps and can be set symmetrical. For more information on WIFI systems and 801.11 standards see Reid (2001), Geir (2002), and Ohrtman et al. (2003).

Because 2.4 GHz WIFI is widely available and costs are very low, a WIFI system can be used to set up high speed data communications link between the farm base of operations and equipment in the field using multiple overlapping WIFI radios broadcasting from the farm's edges inward, much like cellular telephone towers overlap and hand off signals as one travels from cell to cell. Such a system for demonstration purposes was set up at the Good Farm in Noxubee County, Mississippi, USA (McKinion et al., 2004). The base station radio used was an Alvarion BreezeAccess access point (AP) radio with an omni antenna located on the highest structure at the headquarters site. The AP radio provided the link to BreezeAccess subscriber units located at three corners of the contiguous 800 hectare farm as shown in Figure 1. A typical subscriber unit (SU) repeater station is shown in Figure 2. At the repeater station, the BreezeAccess was directly connected to BreezeNet AP radio which then broadcast its signal into the farm property using a sectorial antenna covering a range of almost 4 km. On each farm tractor, combine or picking machine, a BreezeNet subscriber radio combined with an omni antenna mounted on the top of the equipment completed the link from the farm headquarters to the equipment in the field. A user data rate of 2 mbps bidirectional was accomplished.

For farms with noncontiguous fields with treelines in between, a different solution was needed. On a large cotton plantation in the Mississippi Delta in Bolivar County, MS, we tested another demonstration system on Perthshire Farms. Because line-of-sight was an issue with various treelines bordering numerous fields of the 5,000+ hectare farm, a Waverider Model 3001 900 MHz AP radio with an onmi antenna mounted on a 60 meter tall guyed tower was used to communicate to eight repeater stations. A Waverider EUM Model 3000 900 MHz subscriber unit completed the link to the farm headquarters with the remainder of the system being the same as the Good Farm. The 900 MHz radio allowed non-line-of-sight

Figure 1. Map of Good Farm located in Noxubee County, Mississippi, USA showing location of wireless local area network base station (light circle) and three repeater stations (dark outline circles) using 2.4 GHz frequency hopping spread spectrum (FHSS) radios to provide seamless coverage of farm cotton acreage. Vehicle and ground personnel use WIFI radios to complete link for scouting applications with uplink being a FHSS radio



operation up to 15 km. In addition to providing high speed bidirectional communication between headquarters and farm machinery, the 900 MHz digital radio system was also used to connect computer systems located at two cotton gins, one close to the headquarters and another 7 km away, allowing rapid communication and system backup from the gin computers to the headquarters computers. Figure 3 shows the geographical layout of Perthshire Farms. The user data rate on this system was 2 mbps up and down.

Both of these farm demonstration systems were connected to the Internet using satellite links while very workable but did not allow fast uplinks to transmit large datasets (from hundreds of megabytes to several gigabytes in size) back to image analysts. To address this problem and to explore wide-area networking, a third radio system was established to demonstrate the effectiveness of wide-area telecommunications (McKinion et al., 2007). In Noxubee County, Mississippi on Prairie Point Road approximately 15 km east of Macon, a 100 meter tall microwave tower owned by Teletec Communications, LLC of Columbus, Mississippi was used to place three 120° sectorial antenna configured to broadcast horizontally polarized signals in the 900 MHz band using Motorola Canopy 900 radios. A diagram depicting the sectorial layout of the area of coverage from the 100 m tall tower is shown in Figure 4. Each antenna broadcast at a different frequency for each sector to prevent interference. Non-line-of-sight signal propagation was achieved up to 14 km in radius from the tower. Line-of-sight connections were made up to 60 km from the tower essentially providing coverage to stationary antennae located in Noxubee County, southern Lowndes County, and northern Kemper County in Mississippi, and western Pickens County in Alabama. Internet access to the system was provided by Teletec using high gain point to point dish antenna with the microwave tower being the receive location and Teletec's 125 meter tower being the originating site located in Columbus , Mississippi, 45 km away. Internet access was provided as a full duplex 18 mbps service to the three sector antenna array at Prairie Point. A user data rate of 2 mbps up and down was achieved. A typical user radio link is shown in Figure 5.

Cellular telephone providers recently have extended Internet services called EV-DO and WCDMA which provide medium speed Internet

Figure 2. Picture of repeater station with sectorial antenna at top, square panel antenna communicating to base station in the middle of the picture and solar panels for power at the bottom of the tower

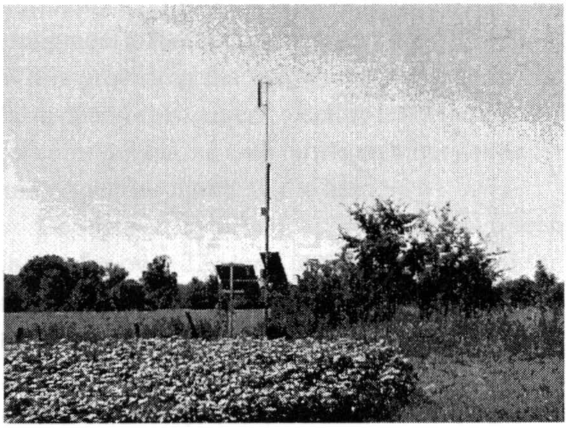


Figure 3. Map of Perthshire Farms, Bolivar County, Mississippi, USA showing size of area covered

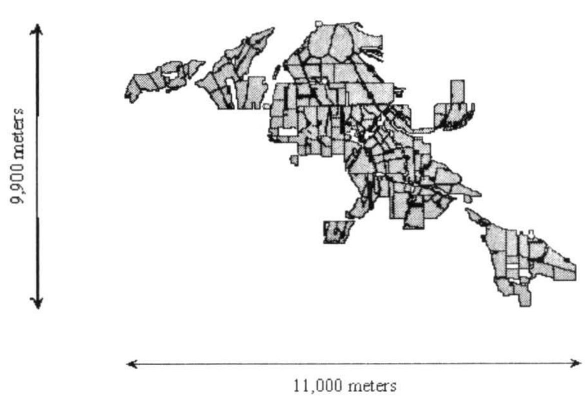


Figure 4. Coverage map indicating the non-line-of sight coverage area advertised by Motorola. 5 km is typical non-line-of sight coverage while we actually were getting 9+ km under non-line-of-sight conditions

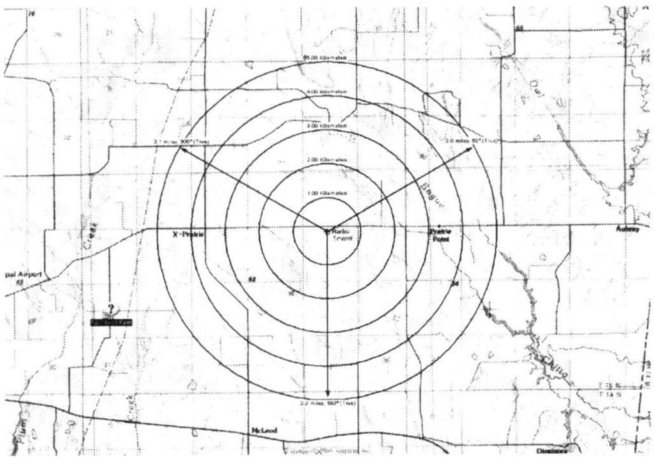
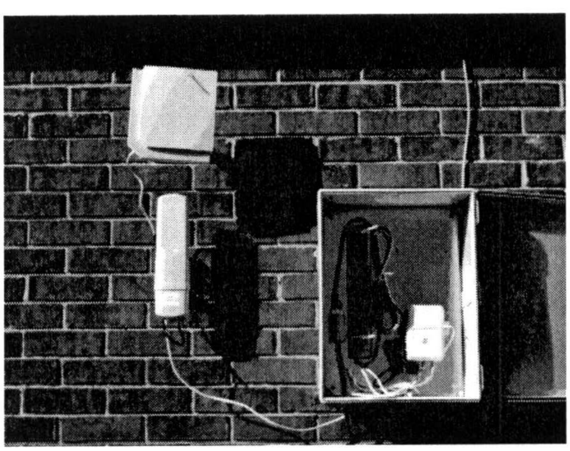


Figure 5. Outdoor antenna mounted at end user site 9 km east of the base station. Antenna and radio are shown on the left with the antenna on top with the radio mounted below. The NEMA 4 box contains the surge protected power strip mounted on the left side interior of the box along with the power converter which supplies 24 VDC power over Ethernet (POE) to the radio, and antenna lightning protector shown mounted on the lower right



and data communication capabilities which serve mobile applications. Cellular services such as CDMA 1xRTT and GPRS, transmit data at speeds less than 200 kbps in one direction and provide customers with access to mobile data applications such as text messaging, e-mail, and ring tone downloads. Wireless *broadband* networks, on the other hand – such as CDMA 1x EV-DO (EV-DO), Wideband CDMA (WCDMA) with High Speed Downlink Packet Access (HSDPA), and Wi-Fi – transmit data at speeds greater than 200 kbps in at least one direction and provide access to the applications available on the slower networks as well as services that require greater bandwidth, such as video programming, music downloads, and high-resolution. Commercial high speed data communications for farm operations are becoming more available, but current data rates are still fairly low with 800 kbps being the standard. The end user also has to face equipment charges and usage charges. Cellular telephone companies are beginning to extend their data communications systems (EV-DO and WCDMA) to rural areas where they already have cellular telephone service.

One very useful service is the coupling of digital paging systems to critical automated systems in farm applications which send a paging signal and brief message telling the recipient that trouble has occurred and what system has been affected. This system could be greatly helped by being included in a digital communication system so that the recipient could not only recognize the nature of the trouble but take steps remotely to fix the problem or stabilize things until someone could come on site to fix the problem.

Licensed broadband Internet access is a strong possibility which promises high speed Internet access and wide area of coverage. This service is known as WIMAX and has been specifically designed for wireless high speed Internet use. Many vendors now have equipment certified by an independent laboratory in Spain as conforming to the WIMAX standard and interoperable with any other vendors certified equipment. While WIMAX may bring high speed Internet to the rural US, most holders of licensed bands are focusing on populated areas to get the highest return on their investment, and the likelihood of rural applications is still several years away.

WIMAX systems promise much higher data rates and greater areas of coverage than WIFI, EV-DO and WCDMA. Because of these two properties WIMAX should be a less expensive commercial service WIMAX was designed from the ground up to be a wide area data communications system and takes advantage of numerous technical advances such as steerable beam forming to achieve range and non-line-of-sight capability as well as much higher user data rates. WIMAX is beginning to be rolled out but because of economics will be available only in the populated areas first.

Future Services

Higher broadcast power satellites have been proposed using highly directional antenna to service smaller areas of the earth with much higher data rates than currently available (Mir, 2008). For most no-time-critical applications, this would be suitable. But where real-time response is needed, satellites present too great a time delay because of distance involved for the space the signal travels.

The ultimate solution is for every home and business in the US to have access to fiber optic cable, but this service will be a long time coming, if ever, because of the cost involved.

A recent Public Notice published by the Federal Communications Commission (http://wireless.fcc.gov/spectrum/index.htm?job=proceedings_details&proid=369) could have a very large impact on rural America's access to high speed digital communications and the Internet. The FCC has proposed that unused bandwidth in the commercial television channels from channel 2 through channel 51 be allowed to be used as unlicensed spectrum with certain limitations as early as January, 2009. For rural areas in particular and for high population density areas of the country, TV whitespace, unused TV channels, promise very high speed data and Internet access over large distances with signal penetration capability properties which all other broadband licensed and unlicensed spectrum do not possess. Where WIFI signals are blocked by buildings and trees, this is TV spectrum, and we all know that TV signals penetrate buildings and propagate through dense foliage and trees. This spectrum will be available for free usage. Each TV channel uses 6 MHz of spectrum. Assuming a data transmission efficiency of 5 bits/hertz, a single channel could be used to transmit 30 mbps of data. For a rural area like Mississippi or Alabama, the most channels broadcasting in either public or commercial channels in an area is about 6 channels plus channel 39 which is reserved for space usage. This means there would be 43 channels available for high speed digital wireless communication, or in terms of capacity, over 1290 mbps with only using omni antennae and not making use of current spectrum reuse technology at all! Limitations on the use of TV whitespace may preclude the use of channels next to broadcasting stations in the lower TV bands, channels 2 thru 13. Data radios will have to have the capability of listening to a channel to ascertain no one is broadcasting on it before the radio attempts to use that channel, otherwise the radio will have to change channels and negotiate the listening process again. All digital radios using TV whitespace will have to be registered with the FCC identifying spectrum to be used and physical location. All radio manufacturers will have to certify and prove to the FCC that their radio equipment will not interfere with public and commercial broadcast stations. These radios will use low power as ordered by the FCC. System builders have said that they can meet all of these requirements. A summary of current wireless technologies is presented in Table 1.

Table 1. Comparison of telephone and wireless local area network protocols; GPRS and EV-DO are used alongside cellular telephone networks while the remainder were designed as wireless data network protocols

Protocol	Upload (mbps)	Download (mbps)	Mode
GPRS	0.02	0.08	Full Duplex
EVDO, Rev a	1.80	3.10	Full Duplex
FHSS, 802.11	2.00	2.00	Half Duplex
WI-FI, 802.11b	10.00	10.00	Half Duplex
802.11a,g	54.00	54.00	Half Duplex
WIMAX, 802.16	70.00	70.00	Half Duplex
802.11n	280.00	280.00	Half Duplex

CONCLUSION

Things have advanced greatly from the early use of telecommunications when the only thing being used was the telephone. Next came unlicensed and licensed radio telephone service. Low powered walkie-talkies were useful for small distances but CB radios and licensed two-way radios quickly became the standard for on-farm communication. Some one way communication was used in land leveling operations which used laser technology so that centimeter accuracy could be obtained in elevation establishment in fields for drainage and irrigation flow. When GPS became available for commercial use, another one way communication technology was rapidly adopted. Hand held GPS units were used to mark field boundaries on computer maps which were spatially registered. This confluence of technology, GPS system and digital mapping, allowed precision farming to begin. GPS also allowed the advent of precision guidance of farm machinery, also called auto-steer. GPS was crucial for the development of microcontrollers placed on farm equipment so that as the field equipment proceeded across the field, the GPS sensor told the equipment where it was so that the microcontroller could vary the rate of the application in response to its control program. These last precision agriculture milestones have all used one-way communication. The time has come to close the loop. As commercial and private high speed networks become available to the farm community, all farm data and information traffic can and should become two-way communication. The potential is there for significant savings in manpower and amplification of effort to improve farm productivity. No longer would data cards have to be delivered to controllers and installed by hand. This could all be handled from the farm operations center by trained personnel making best use of their time and effort. Application maps delivered to the wrong piece of equipment could be totally prevented. All equipment could be tracked in real time at the farm operations center. This means that as supplies are being used and applied in the field, operations can track and anticipate delivery of additional supplies to optimize use of farm machinery and personnel.

The availability of systems for use in TV whitespace spectrum could and should have a major impact in rural America. The potential is enormous with bandwidth capacities exceeding that of current state-of-the-art 750 MHz digital cable systems and being equal to or exceeded by only fiber-optic-to-the-curb systems. If this system is put into place in rural America, the digital divide between rural America and urban America will cease to exist.

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KEY TERMS

CDMA: Code division multiple access, a coding methodology for digital radio transmission which improves the amount of information carried by each hertz of frequency. WCDMA is *broadband* CDMA, a further refinement.

DSSS: Direct sequence spread spectrum digital radio transmission methodology which spreads the radio signal over a range of contiguous frequencies to achieve noise immunity.

EV-DO: Evolution Data-Optimized = high-speed mobile data standard used by CDMA=based networks

GIS: Computer based geographic information system technology which records and/or manipulates map data using a map coordinate system to reference map values by pixels.

GPRS: general packet radio service is a standard for wireless communications that allows packets of data, such as e-mail and Web content, to travel across a wireless telephone network and to the Internet.

GPS: The collection of 24 satellites in low earth orbit which transmit precise time information so that receivers can precisely located themselves on the surface of the earth.

Geo-Referenced Map: A computerized map in which each pixel has a value and a geographic information system location reference.

FHSS: Frequency hopping spread spectrum digital radio transmission methodology in which the radio signal is spread over a narrow range of spectrum and the signal hops in a pseudo-random order to other narrow ranges all within a defined overall range to achieve better noise immunity than DSSS, greater range than DSSS and inherent signal security.

Omni and Sectorial Antennae: An omni antenna broadcasts/receives in a 360° pattern completely covering an area while a sectorial antenna broadcasts/receives in a more narrowly defined direction such as 30°, 60°, 90° , or 180° patterns

Precision Agriculture: The practice of planting, applying chemicals, and recording harvest yields based on GIS and GPS information directed by a prescription map using variable rate controllers/recorders on farm machinery.

Prescription Map: A geo-referenced map which contains rate information so that variable rate controllers can apply the appropriate application to the appropriate location using real time GPS sensor information.

TV Whitespace Spectrum: Each television channels occupies 6 MHz of spectrum and in rural Americal there are typically only 6 to 8 channels in use from the set of channel 2 thru channel 51; the unused chanels in this spectrum are called whitespace.

WI-FI: A DSSS radio system based on industry standard IEEE 802.11b which uses the 2.4 GHz signal spectrum, also called wireless fidelity has a range of 10 km line-of-sight and a bandwidth of 11 Mbps.

WIMAX: Wireless metropolitan area network standard IEEE 801.16 which is the new wireless broadband with a range of up to 80km with a bandwith of up to 75Mbps and is the successor to WI-FI.

ENDNOTE

1 Mention of trade names is for information purposes only and does not imply a recommendation or endorsement by the USDA-ARS.

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